Draft Technical Memorandum

To: Columbia River CWR Project Team

From: John Palmer

Date: October 31, 2017 Version

Subject: Estimating the Number of Steelhead using CWR in the Bonneville Reservoir Reach

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This memo describes an approach used to estimate the number of steelhead within cold water refuges (CWR) in the Bonneville Reservoir Reach of the Columbia River *during the period of maximum CWR use* (mid-August to early-September) using steelhead passage and timing information from the Columbia River DART and previous research on steelhead migration behavior in the Columbia River. Both the total number of steelhead are estimated along with the number and density of steelhead *within each CWR area* using EPA CWR volume estimates.

Figure 1 displays mean daily steelhead counts at Bonneville and The Dalles dams along with associated mean daily water temperatures for the 2007-2016 period. From mid-July (when river temperatures reach about 20C) to September 1 (when river temperatures begin to decline), a significant number of steelhead pass Bonneville Dam but do not pass The Dalles Dam as reflected by the difference between the red line (BON passage counts) and the green line (TDA passage counts), which results in the accumulation of steelhead in the Bonneville Reach. During this period, most of the steelhead are delaying upstream migration and holding in Bonneville Reach CWR before proceeding upstream when Columbia mainstem temperature are cooler in September and October.

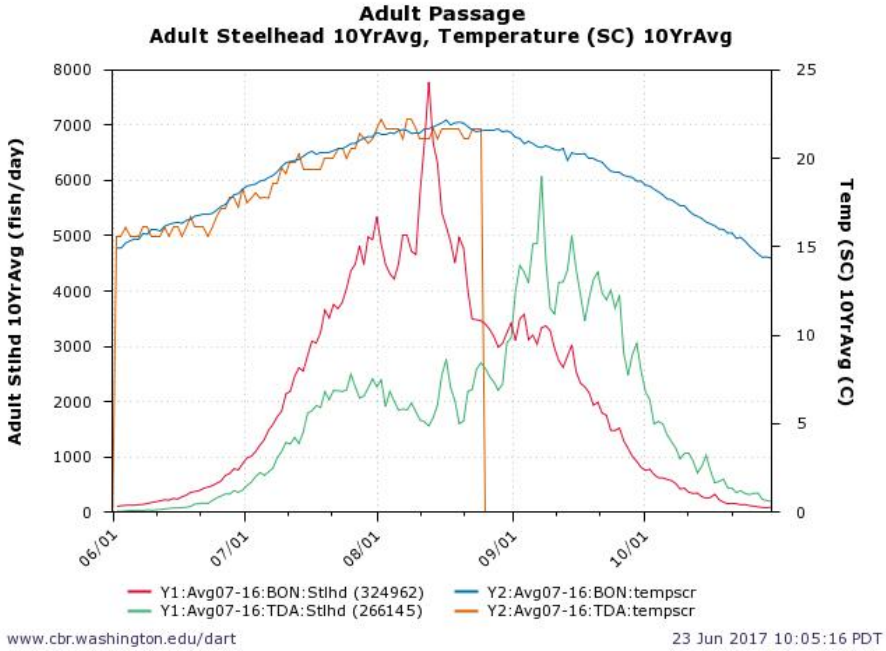

Figure 1 – Adult Steelhead Passage and Water Temperature at Bonneville Dam and The Dalles Dam (2007-2016 Average)

Number of Steelhead in Bonneville Reach CWR

Figure 2 depicts the average estimated number of steelhead that are in the Bonneville Reach for each day from June through October (yellow line) and an estimate of the number of steelhead in CWR for each day when temperatures exceed 20C (green line). The daily values used to generate each of the lines in Figure 2 are displayed in Table 1.

Calculations and Assumptions

A portion of the steelhead that pass Bonneville Dam is not expected to pass The Dalles Dam due to entry into natal tributaries to spawn, return to hatcheries, or harvest within the Bonneville Reach. The percentage expected to not pass The Dalles Dam is estimated to be 18% based on comparing the average annual number of steelhead passing Bonneville Dam (209,078) versus The Dalles Dam (171,235) over the June 1 – October 31 period (2007-2016). Thus, for purposes of calculating the accumulation of steelhead in the Bonneville Reach in Figure 2, 18% of the steelhead that pass Bonneville Dam are removed from the analysis. To calculate the accumulation of steelhead in the Bonneville Reach, the net number of steelhead for each day (Bonneville steelhead passage minus 18% minus The Dalles steelhead passage) is calculated and then summed (see Table 1).

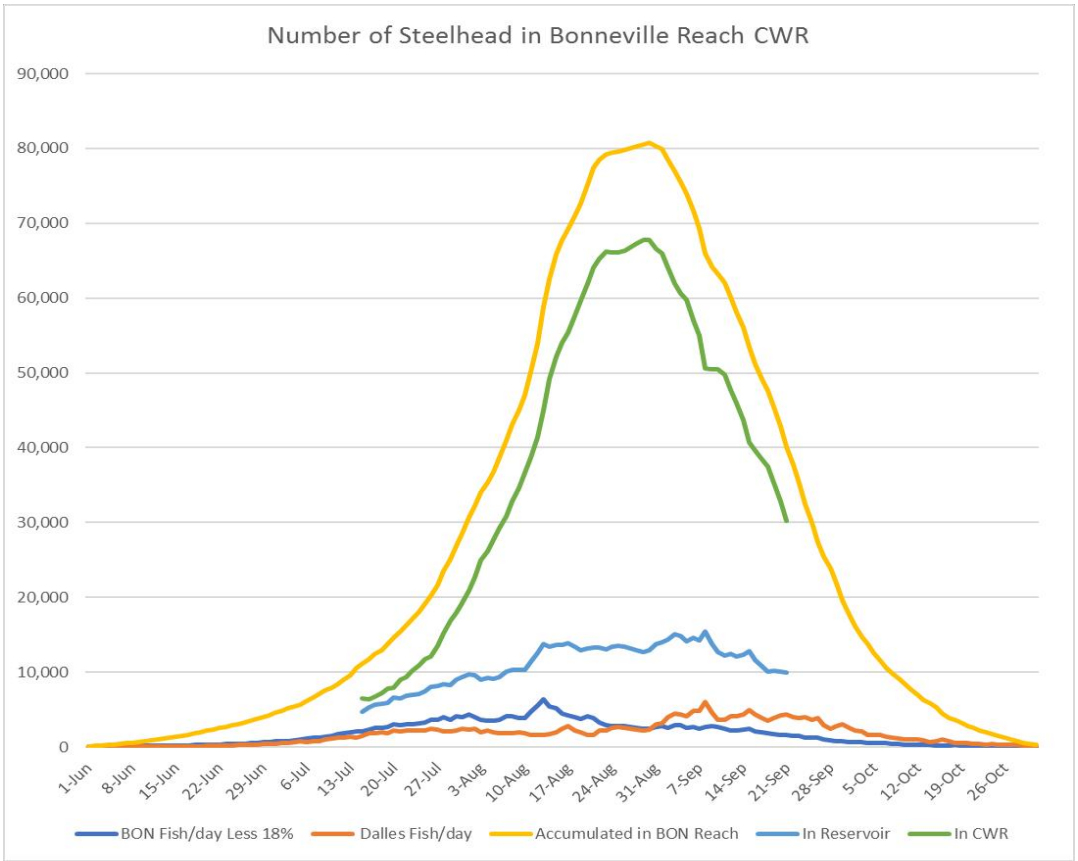

Figure 2 – Accumulation of Steelhead in the Bonneville Reach and the Number of Steelhead in CWR (2007-2016 Average) During the Mid-July to September Target Period

To estimate the number of steelhead in the Bonneville Reach that are in CWR versus in the Bonneville Reservoir, the number of steelhead passing Bonneville Dam and The Dalles Dam on a given day plus 10% of the accumulated steelhead are assumed to be in the reservoir and the rest were assumed to be in CWR. The basis for this is as follows: When temperatures exceed 20C, studies indicate most steelhead will seek CWR or will swim quickly (i.e., not linger) in the reservoir (High et. al., 2006; Keefer et. al. 2004; Keefer et. al. 2009; Keefer and Caudill 2017). Studies also show that when not using CWR, steelhead on average swim from the Bonneville Dam fish ladder to The Dalles Dam fish ladder in 2.3 days covering 75 km (47 miles) at 31 km/day or 1.3 km/hour (Ibid). Thus, assuming one day of reservoir travel for all steelhead passing the Bonneville Dam and another day of reservoir travel for all steelhead passing The Dalles Dam on a given day covers most of the expected total reservoir travel time that an individual steelhead is expected to have in the Bonneville Reach. Adding an additional 10% of the accumulated steelhead assumed to be in the reservoir accounts for additional travel time in the reservoir. These assumptions are generally consistent with results in Keefer and Caudill (2017) indicating 141 steelhead using CWR were in CWR for an average of 20 days, suggesting that about 90% of the time (20 days) steelhead are in CWR and 10% of the time (2.3 days) steelhead are in the reservoir traveling.

Table 1 – Daily Estimate of Number of Steelhead in Bonneville Reach and in CWR (2007-2016 Average)

mm/dd	BON Passage Fish/day	BON Fish/day Less 18%	Dalles Passage Fish/day	Net in BON Reach	Accumulated in BON Reach	In Reservoir	In CWR	% in CWR
1-Jun	96.5	79	19.2	60	60			
2-Jun	106.6	87	19.4	68	128			
3-Jun	118.7	97	18.3	79	207			
4-Jun	127	104	25.5	79	286			
5-Jun	128.9	106	32	74	359			
6-Jun	127.2	104	32.5	72	431			
7-Jun	138.5	114	36.1	77	509			
8-Jun	142.6	117	29.7	87	596			
9-Jun	160.8	132	45.5	86	682			
10-Jun	177.4	145	38.1	107	790			
11-Jun	191	157	44.8	112	901			
12-Jun	206.7	169	50.6	119	1,020			
13-Jun	226.9	186	58.3	128	1,148			
14-Jun	220.1	180	71.2	109	1,257			
15-Jun	251.6	206	77.8	129	1,386			
16-Jun	239.3	196	79.2	117	1,503			
17-Jun	281	230	85.1	145	1,648			
18-Jun	310.3	254	91.1	163	1,812			
19-Jun	359.6	295	108.2	187	1,998			
20-Jun	377	309	150.3	159	2,157			
21-Jun	392.4	322	156.9	165	2,322			
22-Jun	433.3	355	168.3	187	2,509			
23-Jun	456.7	374	158.7	216	2,725			
24-Jun	481.7	395	210.6	184	2,909			
25-Jun	522.1	428	259.5	169	3,078			
26-Jun	564.5	463	293.9	169	3,247			
27-Jun	667.9	548	331.4	216	3,463			
28-Jun	699	573	330	243	3,706			
29-Jun	788.1	646	392.8	253	3,960			
30-Jun	766.7	629	363.3	265	4,225			
1-Jul	878.3	720	400.3	320	4,545			
2-Jul	985	808	483.7	324	4,869			
3-Jul	1013.5	831	545.2	286	5,155			
4-Jul	1098.5	901	644.1	257	5,411			
5-Jul	1214.4	996	719.3	277	5,688			
6-Jul	1314.6	1,078	670.1	408	6,096			
7-Jul	1485.7	1,218	732.7	486	6,581			

8-Jul	1591.7	1,305	797.3	508	7,089			
9-Jul	1730.3	1,419	991.4	427	7,517			
10-Jul	1826.4	1,498	1100.1	398	7,914			
11-Jul	2142.8	1,757	1264.1	493	8,407			
12-Jul	2186.1	1,793	1233.4	559	8,966			
13-Jul	2459.1	2,016	1354.4	662	9,629			
14-Jul	2612.6	2,142	1248.3	894	10,523			
15-Jul	2554.1	2,094	1446.8	648	11,170	4,658	6,512	58%
16-Jul	2833.1	2,323	1794.3	529	11,699	5,287	6,412	55%
17-Jul	3094.7	2,538	1835.8	702	12,401	5,614	6,787	55%
18-Jul	3061.3	2,510	1930.2	580	12,981	5,739	7,242	56%
19-Jul	3251.8	2,666	1893.9	773	13,753	5,936	7,818	57%
20-Jul	3656.2	2,998	2179.4	819	14,572	6,635	7,937	54%
21-Jul	3516.2	2,883	2036.2	847	15,419	6,461	8,958	58%
22-Jul	3758.9	3,082	2204.2	878	16,297	6,916	9,381	58%
23-Jul	3683.5	3,020	2198.3	822	17,119	6,931	10,189	60%
24-Jul	3793.2	3,110	2186	924	18,044	7,101	10,943	61%
25-Jul	4049.8	3,321	2211.9	1,109	19,153	7,448	11,705	61%
26-Jul	4366	3,580	2499.5	1,081	20,233	8,103	12,131	60%
27-Jul	4488.8	3,681	2271.3	1,410	21,643	8,116	13,527	62%
28-Jul	4818.2	3,951	2066	1,885	23,528	8,370	15,158	64%
29-Jul	4486	3,679	2102.6	1,576	25,104	8,292	16,812	67%
30-Jul	4981.8	4,085	2250	1,835	26,939	9,029	17,910	66%
31-Jul	4929.5	4,042	2414.9	1,627	28,566	9,314	19,252	67%
1-Aug	5344.7	4,383	2273.2	2,109	30,676	9,723	20,952	68%
2-Aug	4847.7	3,975	2390.5	1,585	32,260	9,592	22,669	70%
3-Aug	4487.6	3,680	1913.7	1,766	34,026	8,996	25,030	74%
4-Aug	4314.4	3,538	2186	1,352	35,378	9,262	26,117	74%
5-Aug	4221	3,461	2010	1,451	36,829	9,154	27,675	75%
6-Aug	4489.2	3,681	1849.4	1,832	38,661	9,397	29,265	76%
7-Aug	5001.6	4,101	1867	2,234	40,895	10,058	30,838	75%
8-Aug	5001.6	4,101	1852.7	2,249	43,144	10,268	32,876	76%
9-Aug	4719	3,870	1977.5	1,892	45,036	10,351	34,685	77%
10-Aug	4665.5	3,826	1818.5	2,007	47,043	10,349	36,695	78%
11-Aug	5801.5	4,757	1666.6	3,091	50,134	11,437	38,697	77%
12-Aug	6694.6	5,490	1636.3	3,853	53,987	12,525	41,463	77%
13-Aug	7780.5	6,380	1562.3	4,818	58,805	13,823	44,982	76%
14-Aug	6686	5,483	1709.3	3,773	62,578	13,450	49,129	79%
15-Aug	6317.6	5,180	1944.3	3,236	65,814	13,706	52,108	79%
16-Aug	5420.6	4,445	2485.4	1,959	67,774	13,708	54,066	80%
17-Aug	5167.4	4,237	2765.7	1,472	69,245	13,928	55,318	80%
18-Aug	4896.7	4,015	2256.8	1,758	71,004	13,372	57,631	81%
19-Aug	4513.6	3,701	2018.8	1,682	72,686	12,989	59,698	82%
20-Aug	4970	4,075	1605.8	2,470	75,156	13,197	61,959	82%
21-Aug	4780.9	3,920	1646.6	2,274	77,430	13,310	64,120	83%
22-Aug	4006.5	3,285	2187	1,098	78,528	13,325	65,203	83%
23-Aug	3493.4	2,865	2221.4	643	79,171	13,003	66,168	84%
24-Aug	3483.4	2,856	2588.7	268	79,439	13,389	66,050	83%
25-Aug	3466.9	2,843	2700.8	142	79,581	13,502	66,079	83%
26-Aug	3406.6	2,793	2607.5	186	79,767	13,378	66,389	83%
27-Aug	3313.3	2,717	2460.8	256	80,023	13,180	66,843	84%
28-Aug	3179.3	2,607	2355.7	251	80,274	12,990	67,284	84%
29-Aug	2987.7	2,450	2208.8	241	80,515	12,710	67,805	84%
30-Aug	3053.1	2,504	2316.8	187	80,702	12,891	67,812	84%
31-Aug	3243	2,659	3065.1	-406	80,296	13,754	66,542	83%
1-Sep	3419.2	2,804	3157.1	-353	79,943	13,955	65,988	83%
2-Sep	3109.1	2,549	3994.7	-1,445	78,498	14,394	64,104	82%
3-Sep	3499.7	2,870	4466.3	-1,597	76,901	15,026	61,875	80%
4-Sep	3580.6	2,936	4341.1	-1,405	75,496	14,827	60,669	80%
5-Sep	3122.4	2,560	4149.8	-1,589	73,907	14,101	59,806	81%
6-Sep	3202.8	2,626	4851.2	-2,225	71,682	14,646	57,036	80%

7-Sep	3044.6	2,497	4864.2	-2,368	69,314	14,292	55,022	79%
8-Sep	3337.3	2,737	6076.3	-3,340	65,974	15,410	50,564	77%
9-Sep	3370.7	2,764	4565	-1,801	64,173	13,746	50,427	79%
10-Sep	3288.2	2,696	3685.3	-989	63,184	12,700	50,484	80%
11-Sep	2967.8	2,434	3588.4	-1,155	62,030	12,225	49,805	80%
12-Sep	2743.5	2,250	4159.2	-1,910	60,120	12,421	47,699	79%
13-Sep	2623	2,151	4166.1	-2,015	58,105	12,127	45,977	79%
14-Sep	2825.4	2,317	4379.8	-2,063	56,042	12,301	43,741	78%
15-Sep	3029.9	2,485	5004.9	-2,520	53,521	12,842	40,680	76%
16-Sep	2544.1	2,086	4394	-2,308	51,214	11,602	39,612	77%
17-Sep	2336.4	1,916	3930.5	-2,015	49,199	10,766	38,433	78%
18-Sep	2266.3	1,858	3464.7	-1,606	47,593	10,082	37,510	79%
19-Sep	2164.5	1,775	3870.9	-2,096	45,497	10,195	35,301	78%
20-Sep	1937.9	1,589	4209.8	-2,621	42,876	10,086	32,789	76%
21-Sep	1989.9	1,632	4344.1	-2,712	40,164	9,992	30,171	75%
22-Sep	1795.1	1,472	3962.8	-2,491	37,673			
23-Sep	1754.1	1,438	3844.3	-2,406	35,267			
24-Sep	1482.4	1,216	4018.1	-2,803	32,464			
25-Sep	1479	1,213	3690.9	-2,478	29,986			
26-Sep	1526.4	1,252	3925.6	-2,674	27,312			
27-Sep	1291.4	1,059	2880.1	-1,821	25,491			
28-Sep	1154.1	946	2482	-1,536	23,955			
29-Sep	1008.5	827	2856.4	-2,029	21,926			
30-Sep	920.3	755	3050.9	-2,296	19,630			
1-Oct	812.9	667	2562.7	-1,896	17,734			
2-Oct	758.8	622	2182.8	-1,561	16,173			
3-Oct	781.1	641	2034.6	-1,394	14,779			
4-Oct	685.1	562	1597.6	-1,036	13,743			
5-Oct	625	513	1644.5	-1,132	12,611			
6-Oct	622.1	510	1597.7	-1,088	11,523			
7-Oct	595.6	488	1402.7	-914	10,609			
8-Oct	573.8	471	1280	-809	9,800			
9-Oct	520	426	1159.3	-733	9,067			
10-Oct	421.2	345	969.1	-624	8,443			
11-Oct	435.3	357	1065.9	-709	7,734			
12-Oct	363	298	1069.1	-771	6,963			
13-Oct	340.8	279	929	-650	6,313			
14-Oct	347.9	285	714.5	-429	5,884			
15-Oct	284.6	233	832	-599	5,285			
16-Oct	255.9	210	1033.8	-824	4,461			
17-Oct	268.1	220	752.7	-533	3,928			
18-Oct	325.6	267	535.5	-269	3,660			
19-Oct	226.9	186	557.3	-371	3,289			
20-Oct	183.7	151	599.2	-449	2,840			
21-Oct	153.6	126	443	-317	2,523			
22-Oct	161.4	132	434.2	-302	2,221			
23-Oct	156.1	128	355.1	-227	1,994			
24-Oct	136.2	112	392.8	-281	1,713			
25-Oct	141.5	116	339.9	-224	1,489			
26-Oct	121.1	99	320	-221	1,268			
27-Oct	110.8	91	342	-251	1,017			
28-Oct	97.5	80	348.3	-268	749			
29-Oct	88.3	72	233.3	-161	588			
30-Oct	83.9	69	212.5	-144	444			
31-Oct	93.5	77	196.8	-120	324			

Results

As shown in Figure 1 and Table 1, steelhead accumulate in the Bonneville Reach until August 30th when the maximum number of steelhead using CWR is estimated to be 67, 812, on average. On August 31th and thereafter, more steelhead are passing The Dalles Dam versus Bonneville Dam and the number of steelhead accumulated in the Bonneville Reach and in CWR begins to decrease.

The peak CWR use period is from mid-August through early-September. From August 15 – September 10, the average number of steelhead in CWR exceeds 50,000 fish each day. During this period, between 80-85% of the steelhead in the Bonneville reach are estimated to be in CWR and 15-20% in the reservoir.

Field Verification

To test the above assumptions on the percentage of accumulated steelhead in the Bonneville reach that are in the reservoir versus in CWR, the location of 219 radio-tagged steelhead from the University of Idaho 2000 and 2002 research studies were analyzed. As shown in Figure 3, the number of steelhead in the Bonneville reach peaked in late August and early September and the vast percentage of steelhead were in CWR (approximately 90%) versus in the reservoir during this period.

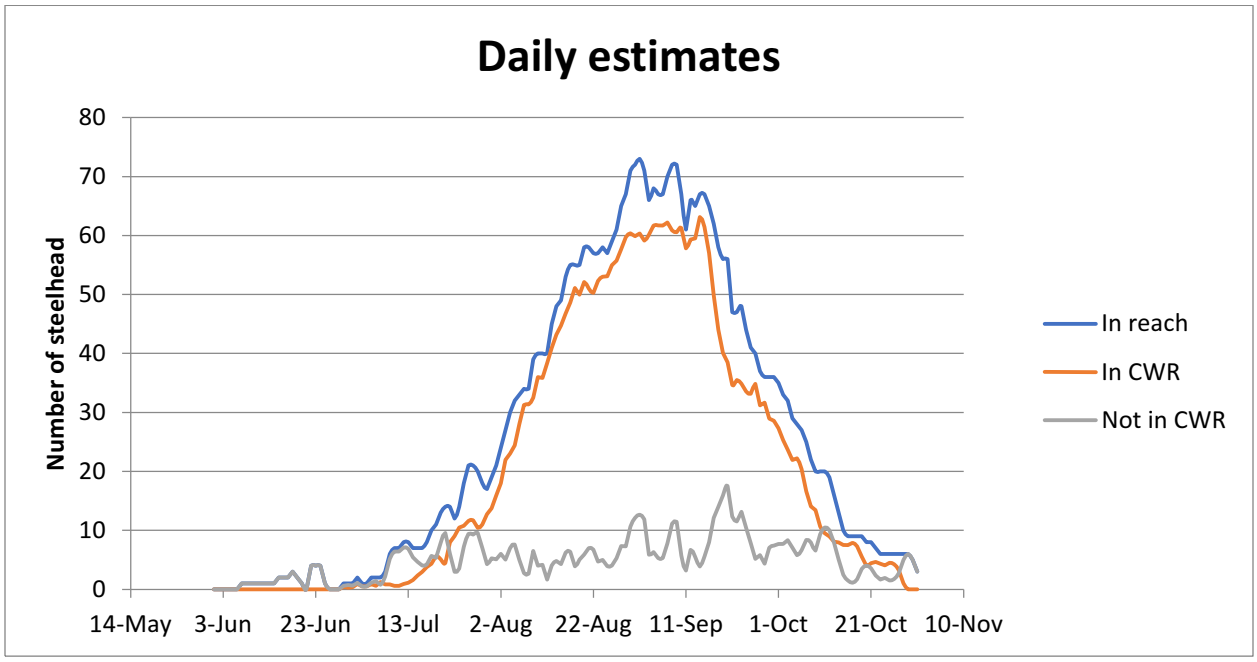

Figure 3 – Distribution of 219 Radio-Tagged Steelhead in Bonneville Reach from University of Idaho 2000 and 2002 Research Studies (Keefer 8/31/17 email)

Simplified Multi-Year Estimate of Number of Steelhead in Bonneville Reach CWR

The above approach estimates the number of steelhead in the Bonneville Reach CWR on a daily basis using daily fish passage numbers at Bonneville Dam and The Dalles Dam. An alternative simplified approach estimates the number steelhead in CWR using total steelhead passage counts at Bonneville Dam and The Dalles Dam for the critical July 15 – August 31 period, when average temperatures exceed 20C and steelhead are accumulating in the Bonneville Reach.

As shown in Table 2, during the July 15 through August 31 period, 209,078 steelhead passed Bonneville Dam on average in 2007-2016, but only 101,670 passed The Dalles Dam. As discussed above, 18% of the steelhead passing Bonneville Dam are estimated to enter tributaries, hatcheries, or are harvested in the Bonneville Reach. Thus, 171,235 (82% of the average count at Bonneville Dam) are expected to ultimately pass The Dalles Dam and would be expected to pass The Dalles Dam during the July 15-August 31 period if were not for temporary use of CWR. 171,235 (expected to pass) minus 101,670 (actually passed) approximates the number of steelhead (69,565) in the Bonneville Reach during the July 15 – August 31 period which are either temporarily in CWR or migrating in the reservoir. The number in the reservoir under this approach is estimated to be 15%, leaving 59,130 in CWR. The 15% was based on the analysis and field verification presented above for the approximate percentage of steelhead in the reservoir versus within CWR during the period of peak CWR use.

The average estimate of 59,130 steelhead in the Bonneville Reach CWR using this simplified approach is consistent with the daily analysis described above in Figure 1 and Table 1. The 59,130 number of steelhead in CWR represents the period of maximum CWR use, which is late-August – early September.

Table 2 – Estimated Number of Steelhead in CWR (2007-2016 Average)

Passed BON	Exp to Pass DAL	Passed DAL	In BON Reach	In CWR
7/15 -8/31	7/15 -8/31	7/15 -8/31	7/15 -8/31	7/15 -8/31
209,078	171,235	101,670	69,565	59,130

Source: Columbia River DART

Table 3 applies the same methodology as described above, but estimates the number of steelhead in CWR for each individual year from 1999 to 2016. As shown, the number of steelhead in CWR varies in response to run size and river environment, ranging from 23,107 during a low-abundance year with below-average water temperatures (2012) to 155,492 during a high-abundance warm year (2009). In 2009 (Figure 3), temperatures reached 20C in mid-July and climbed steeply to 23C by early August resulting low passage at The Dalles Dam relative to passage at Bonneville Dam and high CWR use during the July 15-August 31 period. Conversely, in 2012 (Figure 4), river temperature did not reach 20C until the 2nd week of August and exceeded 20C for just a few weeks, resulting in high passage at The Dalles Dam relative to passage at Bonneville Dam and low CWR use during the July 15-August 31 period.

Table 3 – Estimated Number of Steelhead in CWR Each Year (1999-2016)

				Measured %	Expected		
	Ave	Passed	Passed	That Passed	to Passed		
	Temp	BON	Dalles	Dalles	Dalles	In BON Reach	In CWR
Year	July 15 -Aug 31	July 15 -Aug 31	July 15 -Aug 31	June 1-Oct 31	July 15 -Aug 31	July 15 -Aug 31	July 15 -Aug 31
2016	21.4	83,919	24,212	80%	66,868	42,656	36,258
2015	21.8	165,138	69,059	84%	137,893	68,834	58,509
2014	21.5	175,686	70,488	80%	140,923	70,435	59,869
2013	21.5	166,926	68,949	83%	138,059	69,110	58,743
2012	20.1	142,032	95,612	86%	122,797	27,185	23,107
2011	19.5	252,331	176,573	82%	207,452	30,879	26,248
2010	21.0	231,804	121,974	82%	189,445	67,471	57,350
2009	21.6	451,509	205,163	86%	388,094	182,931	155,492
2008	20.0	225,506	117,044	79%	177,048	60,004	51,004
2007	21.1	229,124	83,820	76%	173,420	89,600	76,160
2006	21.1	187,415	53,379	72%	134,561	81,182	69,005
2005	21.4	175,028	55,866	77%	135,090	79,224	67,340
2004	22.0	155,516	42,744	78%	120,905	78,161	66,437
2003	21.7	209,328	58,083	77%	160,904	102,821	87,398
2002	20.4	257,857	131,121	82%	210,238	79,117	67,250
2001	20.7	397,879	169,554	80%	319,544	149,990	127,491
2000	20.6	164,593	75,954	75%	124,114	48,160	40,936
1999	20.0	136,136	76,782	77%	104,458	27,676	23,524
Average	20.9	219,048	98,363		175,585	77,222	65,639

Source: Columbia River DART

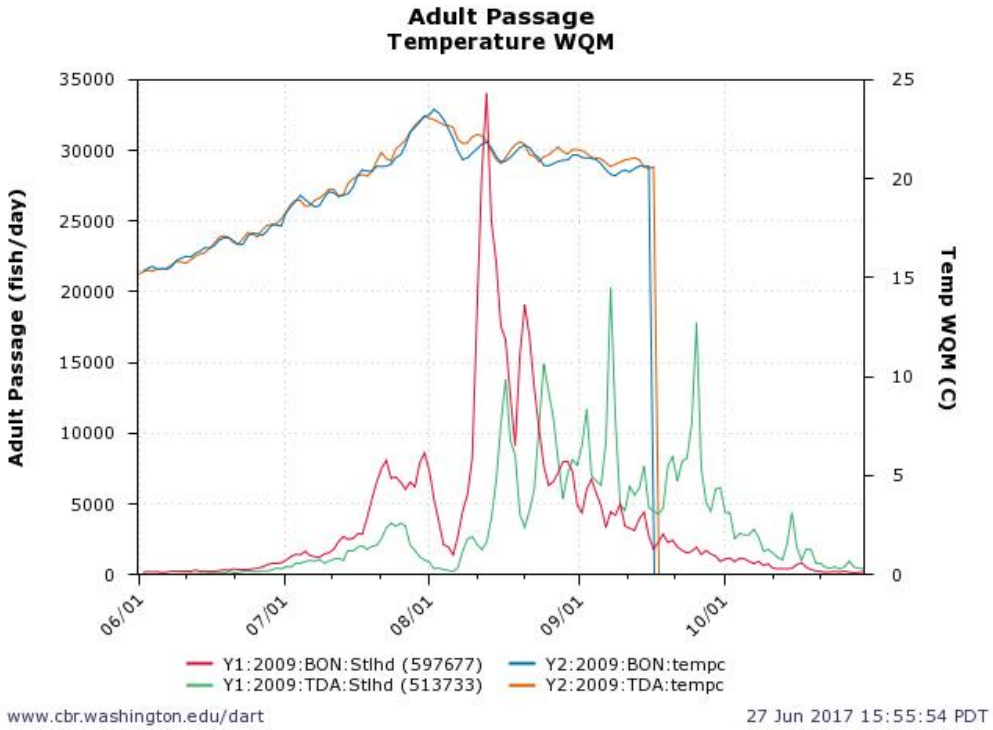

Figure 4 – Adult Steelhead Passage and Water Temperature at Bonneville Dam and The Dalles Dam During a Year with High Steelhead Returns and Above Average Temperatures (2009)

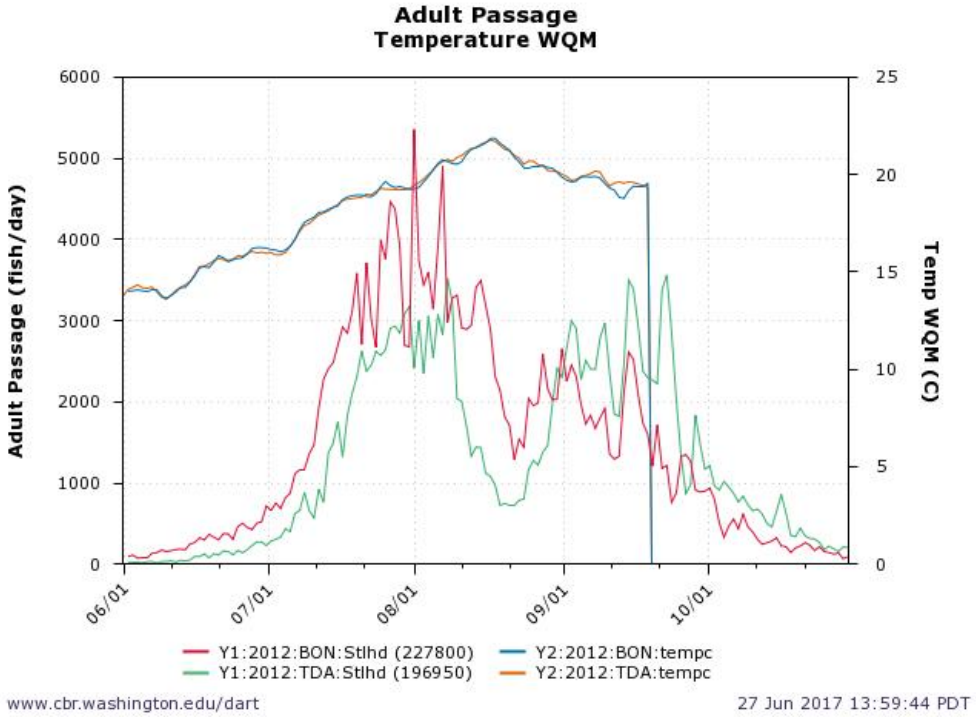

Figure 5 – Adult Steelhead Passage and Water Temperature at Bonneville Dam and The Dalles Dam During a Year with Low Steelhead Returns and Below Average Temperatures (2012)

Research studies document how the use of CWR by steelhead increases as temperature increases above 19C (Keefer et. al., 2009). It's also logical that the number of steelhead in CWR is also a function of the size of the steelhead run. Thus, the number of steelhead in CWR is a function of both water temperature and the size of the run. Using data in Table 3, the following multiple linear regression (R^2=0.95) was developed to predict the number of steelhead in CWR during the period of maximum CWR use based on the average temperature and the cumulative Bonneville Dam steelhead passage for the July 15-August 31 period.

# of Steelhead in CWR = 23722.35 (Ave $T_{July\ 15\text{-}Aug\ 31}$) + 0.328729 (# $Steelhead_{July\ 15\text{-}August\ 31}$) – 503,150

Number of Steelhead in Each CWR Area

EPA has identified 26 CWR areas and associated CWR volumes between the Columbia River mouth and the Snake River confluence, eight of which are in the Bonneville Reach and are shown in Table 4. A total of 1,784,298 m^3 of CWR (greater than 2C cooler than the Columbia River) is estimated to occur in this reach. The majority (62%) occurs in Drano Lake (Little White salmon), followed by the Klickitat River (12%), Herman Creek (10%), and the White Salmon River (9%). Table 4 includes the estimated number of steelhead in each of the eight CWR areas for an average year, a high abundance year, and a low abundance year assuming steelhead are distributed proportionately to CWR volume. For example, an average of 36,490 steelhead are estimated to temporarily use Drano Lake as CWR each day during the period of maximum CWR use (mid-August through early September) during an average year, ranging from 14,260 during a low year and 95,957 during high year.

Table 4 – Estimated Number of Steelhead in Each Bonneville Pool CWR (>2C Δ CWR)

Tributary Name	Tributary Temp	Total CWR Volume (> 2°C Δ)	% of CWR in BON Reach	# Steelhead in Each CWR (2007-2016 Ave)	# Steelhead in Each CWR High Year (2009)	# Steelhead in Each CWR Low Year (2012)
	°C	m3				
Eagle Creek	15.1	2,988	0.2%	99	260	39
Rock Creek	17.4	1,708	0.1%	57	149	22
Herman Creek	12.0	169,698	9.5%	5,624	14,788	2,198
Wind River	14.5	105,220	5.9%	3,487	9,169	1,363
Little White Salmon River	13.3	1,101,126	61.7%	36,490	95,957	14,260
White Salmon River	15.7	153,529	8.6%	5,088	13,379	1,988
Hood River	15.5	28,000	1.6%	928	2,440	363
Klickitat River	16.4	222,029	12.4%	7,358	19,349	2,875
Total		1,784,298	100%	59,130	155,492	23,107

Studies indicate that steelhead seek cold water (8-18C) when temporarily staying in CWR, thus a better indicator of CWR volume may be the volume less than 18C (Keefer and Caudill 2017). Table 5 displays the same information as Table 4, except just for CWR less than 18C, which is estimated to be 954,176 m^3 for the Bonneville Reach. The distribution of CWR volume and steelhead is roughly the same under this scenario, with most CWR volume/steelhead in Drano Lake/Little White Salmon (56%), followed by the Klickitat River (16%), Herman Creek (10%), and the White Salmon River (10%).

Table 5 – Estimated Number of Steelhead in Each Bonneville Pool CWR (<18C Δ CWR)

Tributary Name	Tributary Temp	Total CWR Volume (< 18°C)	% of CWR in BON Reach	# Steelhead in Each CWR (2007-2016 Ave)	# Steelhead in Each CWR High Year (2009)	# Steelhead in Each CWR Low Year (2012)
	°C	m3				
Eagle Creek	15.1	1,498	0.2%	93	244	36
Rock Creek	17.4	1,204	0.1%	75	196	29
Herman Creek	12.0	95,656	10.0%	5,928	15,588	2,316
Wind River	14.5	64,810	6.8%	4,016	10,561	1,569
Little White Salmon River	13.3	535,650	56.1%	33,194	87,289	12,972
White Salmon River	15.7	95,529	10.0%	5,920	15,567	2,313
Hood River	15.5	7,500	0.8%	465	1,222	182
Klickitat River	16.4	152,329	16.0%	9,440	24,823	3,689
Total		954,176	100%	59,130	155,492	23,107

Comparison to Field Studies

In 2000, of 243 radio-tagged steelhead documented in Bonneville Reach CWR, 144 (59%) were detected in the Little White Salmon River/Drano Lake, 33 (14%) were detected in Herman Creek/Cove, 30 (12%) were detected in the White Salmon River, 20 (8%) were detected in the Wind River, 15 (6%) were detected in the Klickitat River, 1 was detected in Eagle Creek, and none were detected in the Hood River (Keefer and Caudill 2017). These data affirm most steelhead CWR use is in the Little White Salmon River/Drano Lake and the estimated proportion of CWR use aligns with the proportion of CWR volume available in each of the eight refuges; except the field data indicates a slightly higher amount of CWR use of Herman Creek and the White Salmon River and a lesser amount of CWR use of the Klickitat River than what is predicted based on CWR volume as shown in Tables 4 and 5. One reason for lesser CWR of the Klickitat River than predicted based on CWR volume is that the Klickitat River delta is shallow at the confluence with the Columbia River and that may impede access up the Klickitat River.

The University of Idaho radio-tagged data for 2000 and 2001 was analyzed on two specific days to see what CWR sites were used on those specific days. Table 6 shows the distribution of steelhead in the Bonneville Reservoir reach for August 7 and August 31. August 7 was chosen to reflect the early phase on accumulation of steelhead in the Bonneville reservoir reach. August 31 was chosen to reflect the time of peak accumulation of steelhead in the Bonneville reservoir reach and maximum amount of CWR use (see Figures 2 and 3). These data confirm the Little White Salmon/Drano Lake and Herman Creek/Cove as the highest used CWR sites. These data also suggest Herman Creek/Cove is used in higher proportion earlier in the season and steelhead tend to accumulate in Little White Salmon/Drano Lake as the season progresses.

Table 6 – Distribution of Radio-Tagged Steelhead in the Bonneville Reach on Two Specific Days (Combined 2000/2001 Data Set) (Keefer 9/11/2017 email)

	August 7	August 31
Below Bonneville Dam	1 (2.9%)	0 (0%)
Bonneville Reservoir	3 (8.8%)	9 (12.5%)
Herman Creek	8 (23.5%)	6 (8.3%)
Wind River	1 (2.9%)	1 (1.4%)
Little White Salmon/Drano Lake	12 (35.3%)	40 (55.6%)
White Salmon	3 (8.8%)	4 (5.6%)
Klickitat River	4 (11.8%)	4 (5.6%)
Unknown CWR	0 (0%)	4 (5.6%)
The Dalles Dam Tailrace/Fishway	2 (5.9%)	4 (5.6%)
Total	34 Steelhead	72 Steelhead

Fish Density in CWR

The fish density within CWR in the Bonneville Reach can be calculated by dividing the number of steelhead estimated to be in CWR by the volume of CWR. Table 7 presents the fish density for the different scenarios presented in Tables 4 and 5. For example, considering just CWR less than 18C, for an average year, the fish density in each of the CWR areas in the Bonneville Reach is estimated to be 155 steelhead per 2,500 m^3 (size of an Olympic swimming pool), ranging from 401 per Olympic pool in a high year and 61 per Olympic pool in a low year.

Table 7 – Estimated Steelhead Density in CWR

	CWR Volume (> 2°C Δ)			CWR Volume (< 18°C)		
	Average	High	Low	Average	High	Low
	2007-2016	2009	2012	2007-2016	2009	2012
# fish/m3	0.0331	0.0871	0.0130	0.0620	0.1630	0.0242
# fish/2500 m3	83	218	32	155	407	61

Historical Analysis of Bonneville Reservoir Reach CWR Use

Since The Dalles Dam was built in 1957, the comparison of steelhead passage at the Bonneville Dam versus The Dalles Dam is available since 1957. As shown in Figure 1 and in this memo, passage data from the last decade shows there is a significant delay in passage over the The Dalles Dam and accumulation of steelhead in the Bonneville Reservoir Reach during the period of summer maximum temperatures. Interestingly, as shown in Figure 6, there is not a significant delay over the The Dalles Dam in the decade after the The Dalles Dam was built (1957-1966). Limited temperature data collected in this decade depicted in Figure 6 also shows summer peak temperatures were lower compared current day temperatures. These data suggest steelhead use of CWR sites in the Bonneville Reach was less historically than what we observe today and that steelhead are using CWR more today in response to increased summer temperatures of the Columbia River.

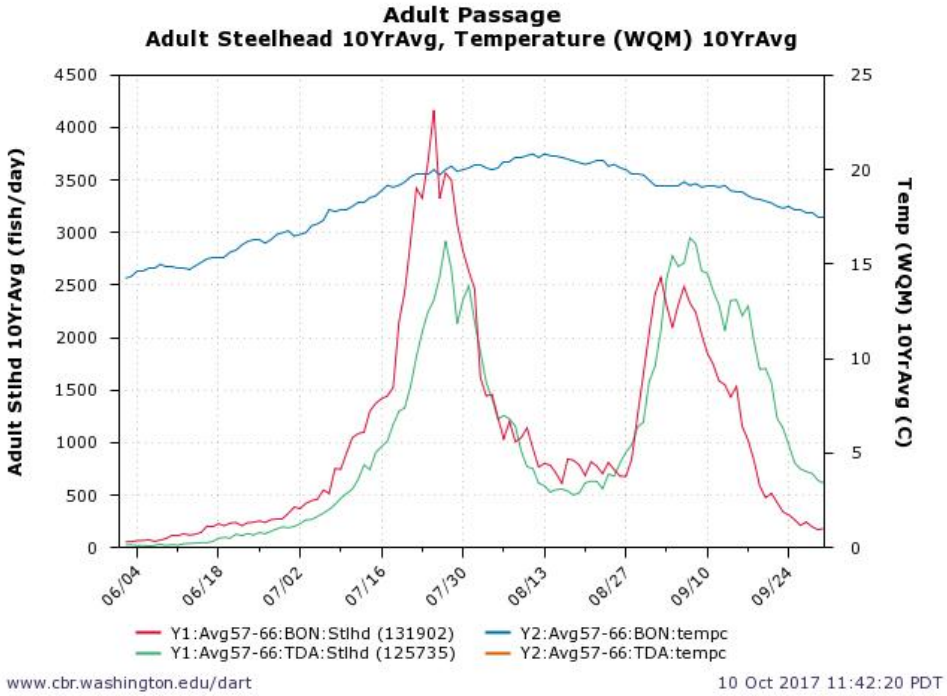

Figure 6 – Adult Steelhead Passage and Water Temperature at Bonneville Dam and The Dalles Dam (1957-1966 Average)

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